

Final Qualification and Early On-Orbit Performance of the HESSI Cryocooler

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ABSTRACT

The High Energy Solar Spectroscopic Imager (HESSI) spacecraft was launched on February 5, 2002. It now observes the Sun with the finest angular and energy resolutions ever achieved from a few keV to hundreds of keV, using an array of nine germanium detectors operating at 75K. The spacecraft was originally scheduled for launch in July 2000, but a vibration facility mishap damaged the primary structure of the spacecraft, along with the cryocooler. This paper describes issues in the qualification of a replacement for the original flight cooler, and describes early on-orbit performance.

INSTRUMENT DESCRIPTION

The High Energy Solar Spectroscopic Imager (HESSI) spacecraft (Figure 1) was selected by NASA in 1997 for its Small Explorer (SMEX) program. Launched in February 2002 after a number of delays, and renamed RHESSI, it should observe thousands of flare events occurring near and slightly after the peak of the eleven-year solar cycle during its planned two years of observations. The spectrometer uses an array of nine large germanium detectors, mounted in a cryostat on a common coldplate. While the detectors themselves have no measurable dissipation, each detector requires two FET amplifiers operating below 150K, each dissipating approximately 30mW.

An off-the-shelf Sunpower M77B Stirling-cycle cryocooler was chosen for the mission. This cryocooler has a pneumatically driven displacer, and an integral counterbalance motor that could be used for vibration attenuation. (Figure 2) The compressor and displacer are each supported on gas bearings, enabling a very long service life. Copper fins intended for air cooling have been machined away to allow for a conductive thermal interface. Mounting tabs that were brazed to the outer housing were removed, and a support cradle was used in its place.¹ The M77 cryocoolers were vibrated to 14.1 grms without any apparent ill effects. The cryocooler was designed for long life, and in fact the first flight model eventually ran for 17000 hrs. But mishaps during instrument-level vibration testing raised a number of questions about the coolers, and a significant effort was eventually required to qualify a second unit for flight.

Engineering Test Unit Cooler (ETU)

The engineering test unit (ETU) cooler was integrated with the ETU spectrometer in March 1999, and demonstrated that the system provided adequate thermal performance. The ETU spectrometer was damaged during its first vibration qual test due to assembly problems, and though the cryocooler seemed at first unaffected, its performance after the vibration test was qualitatively different than before. It required slightly more power to reach operating temperature, and the coldfinger temperature

showed an instability which was at first attributed to electrical noise on the sensor. But the ETU cryocooler remained in operation for six months, before finally being retired, along with the ETU spectrometer assembly.

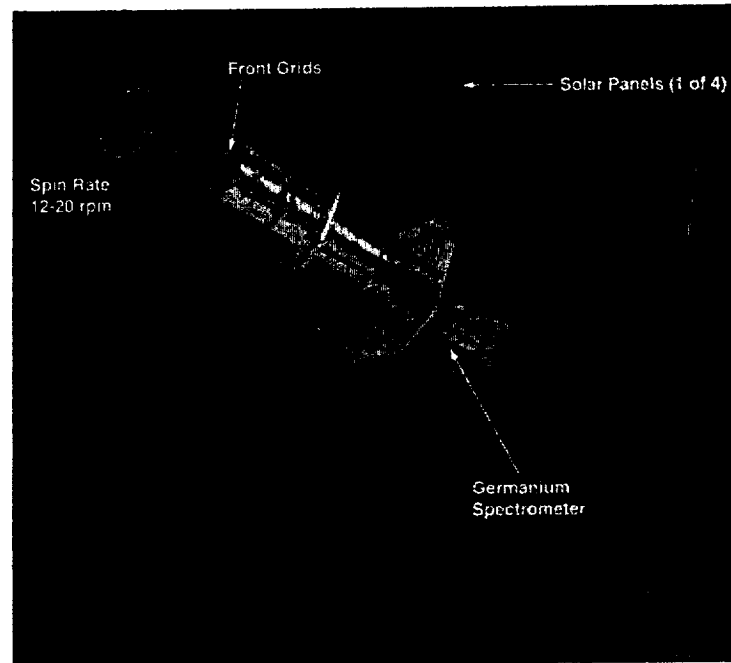


Figure 1 The RHESSI spacecraft.

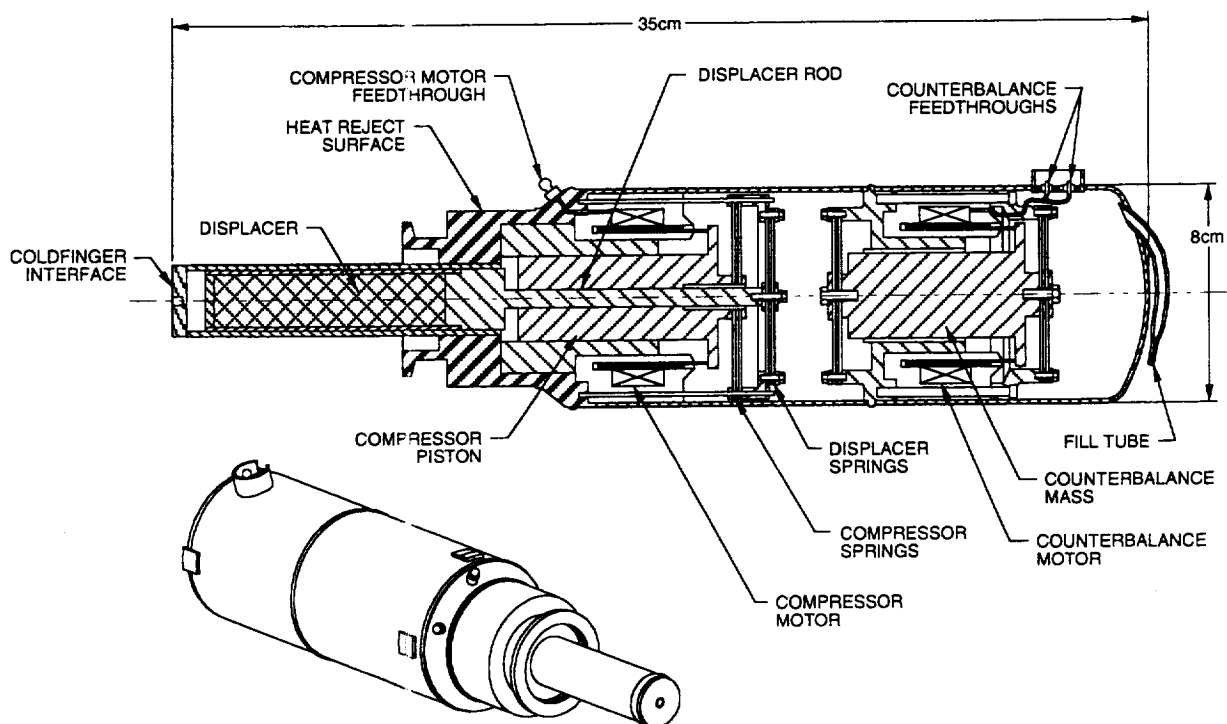


Figure 2. Layout of an M77B Sunpower Stirling-cycle cooler.

First Flight Model Cooler (FM1)

The first flight model cooler (FM1) was integrated into the FM spectrometer in September 1999, and immediately put into an instrument-level vibration test. Subsequent thermal performance was satisfactory, and the cooler continued in operation until March 21 2000, when the spacecraft, with the spectrometer and all other flight systems integrated into it, was subjected to an accidental overtest during final vibration qualification.² The solar panels and the telescope support ring were broken, and the main deck of the spacecraft was deformed beyond allowable tolerances. The spectrometer was removed from the spacecraft for testing, and the cryocooler was found to require significantly higher power to achieve operating temperature. In addition, the performance of the cryocooler had become much more sensitive to its orientation relative to gravity, and the coldfinger temperature was highly unstable. The backup cooler, then in final qualification testing, was found to be overstroking at high power levels that had not previously been a problem, and so a search began for a replacement unit that would be eligible for flight.

RECOVERY EFFORT

The ETU and FM1 cryocoolers had come from an initial batch of eight M77B cryocoolers manufactured in 1994. Of the other six units, two were damaged in removing the copper cooling fins, two were damaged during bakeout operations, one had a counterbalance that was damaged during development of vibration control software, and one developed an intermittent electrical problem. A second batch of eight coolers, M77C units without integral counterbalancers, was produced in 1999, but problems with the cleaning process at GSFC apparently caused other problems in the cooler, and all eight, including the first flight backup cooler, were eventually excluded from flight. At that point, the M77B with the damaged counterbalance was judged to be the best available option for flight, while a new backup cooler was ordered from Sunpower.

Failure Mode Analysis

The team examining the options for RHESSI was concerned about failure modes for the coolers, including:

1. Mechanical and structural failures, such as the internal support structure, compliant feed through rods, spring assemblies, or the loosening of mechanical attach hardware (i.e. screws and nuts).
2. Contact of moving parts, either piston or motor, with stationary cryocooler structure, such as the cylinder and feed through surfaces.
3. Contamination of the internal helium working fluid either by water or particulates.
4. Electrical failure (either an electrical short or open).
5. Working fluid leakage from the cryocooler structural housing or working fluid fill tube.

Both the ETU and FM1 coolers were inspected for mechanical and structural failures after removal from the RHESSI spectrometers. The EM cooler coldfinger was out of alignment with the rest of the assembly by about 0.25° , or .3mm at the cold end, and the FM1 coldfinger about 0.09° , or 0.1mm. It was not possible to determine if the

coldfinger had been deformed, or if internal components had shifted. One nut had come loose in the FM1 cooler, on a joint in the counterbalance assembly that was not critical to alignment. Analysis of the vibration loading on the coldfinger suggested that there was a large margin on the yield strength of the coldfinger, but no verification testing was performed on an actual coldfinger. The team felt that it was possible that the coldfinger misalignment had caused the loss of thermal performance, but was unable to conclude what had caused it.

The team considered a number of different ways to check the cryocoolers for contact between the moving and stationary parts. Low-frequency stiction testing is not possible with these coolers, since the gas bearings are not functional at low amplitude / low frequency, and there is no position sensor to indicate piston position. X-ray examination does not give adequate resolution of the materials in the coldfinger. Vibration measurements of the cryocooler body do not show a distinct signature of touch contact among the large existing forces of normal vibration. The team did commission an analysis of the gas bearings, and found that the bearings should be able to adequately support the pistons under one-G operation, as well as in the 15rpm rotational environment of the spacecraft.

Prior to disassembly the ETU and FM1 coolers were run in a variety of orientations, showing that thermal performance was not only dependent on whether the coldfinger was pointing up or down, but even on which side of the cryocooler was down when the cryocooler was run horizontally. This sensitivity to roll angle, as well a test with the ETU in which weights were hung on the coldtip during operation, strongly suggested that the components in the coolers were rubbing in certain operating orientations. This roll angle sensitivity became one test for touch contact in flight candidate cryocoolers.

The working gas in the ETU and FM1 coolers was sampled with a residual gas analyzer, finding that it was contaminated with a small amount of CO and CO₂, but no measurable water. While the gas contamination levels did not seem to have affected the thermal performance, there was a significant amount of dust buildup in the assemblies, probably due to touch contact during wear-in of the machines. The flow impedance of the gas bearings had changed from the initial manufacture, possibly due to accumulation of dust in the bearing ports. It seemed possible that dust deposits might accumulate benignly, only to be kicked loose into a bearing port during a vibration test. While this scenario was not eliminated in the ETU or FM1 coolers, it seemed unlikely to affect the FM2 cooler, which had already been vibrated four times prior to launch, with no apparent ill effect.

No indications were found in the ETU or either of the FM coolers of any electrical problems, or any helium leakage from the pressure boundary of the machine.

Selection of FM2

After consideration of all the available M77 coolers, extensive testing of the primary candidates, and analysis of the sensitivity of the science mission to delays in the launch, relative to the maximum in the solar flare cycle, the cooler with the damaged counterbalance was selected as the FM2 cooler, and installed in the FM spectrometer in September 2000.

OPERATION OF FM2

The spectrometer was again put into vibration prior to thermal characterization. When the cryocooler was eventually cooled down, it was found to give adequate thermal performance, holding the detector temperature at 78K for 67w of input power. This was slightly higher than the FM1 cryocooler, but there was no way to determine if the cooler performance was a little low, or if items such as the spectrometer MLI had degraded during service and handling of the system.

Malfunction of electronics box

During spacecraft-level testing, the main computer crashed, cutting off the clock that drove the output waveform of the cryocooler's power amplifier. The cooler was inadvertently spared the application of the full 28VDC bus voltage across its terminal, as a small instability in the amplifier drove it into un-clocked oscillation at about 3Hz. The electronics were modified to eliminate the dependence on the spacecraft clock, and the cryocooler was found to still be in good operating condition.

Final Instrument Warmup

The spectrometer was kept cold almost continuously from the time it came out of vibration testing to the time it was mated to the launch vehicle, in an effort to keep the detectors cold enough to avoid incidental cosmic ray damage. Due to a series of mishaps with the Pegasus family of launch vehicles, the launch date slipped from 2001 into February of 2002. During most of this time, liquid nitrogen was used to maintain the temperature, allowing the cryocooler to remain dormant. The cooler was used for the last time in January 2002, to control the internal temperature distribution of the spectrometer during the final pre-launch warmup to room temperature.

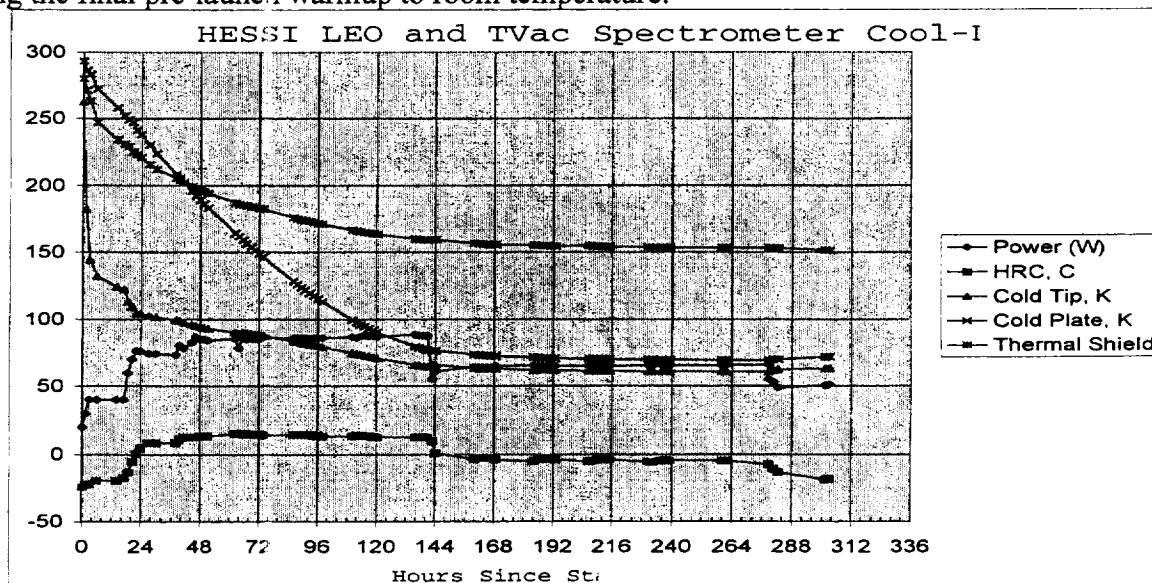


Figure 3 On-orbit cooldown of the spectrometer.

LAUNCH AND EARLY OPERATIONS

The spacecraft was launched February 5, 2002, with power applied to the cryocooler about eight hours after launch. The detectors reached an operating temperature of 65K over the next six days, with about 90W going into the cooler. (Figure 3) The power was subsequently trimmed back to about 50W, to maintain a coldplate temperature of 72-75K. The cooler performance compares well with data from spacecraft thermal/vacuum testing, indication that the cooler performance was not measurably affected by the actual launch environment. The system has now operated for about twenty weeks on-orbit, with no indication of any change in performance

CONCLUSIONS

The M77 cooler seems to have been successfully put into service on-orbit on the RHESSI spacecraft. Though not originally intended for flight use, it was possible to qualify individual units for flight, and show with some confidence that they have good potential for lasting through a two-year mission. Due to the low number of coolers produced, and the variability from unit to unit, it is very difficult to say what the overall reliability might be.

1 Boyle, R., Banks, S., Cleveland, P. and Turin, P., "Design and Performance of the HESSI Cryostat," *Cryogenics* **39** (12), 1999, pp. 969-973.

2 Report on High Energy Solar Spectroscopic Imager (HESSI) Test Mishap, http://apollo.ssl.berkeley.edu/pub/hessi/JPL_Mishap/HESSI_MIB_vol1.pdf